

Cu-8 Cr-4 Nb: A New Alloy For Rocket Engine Combustion Chambers

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Outline

- X-33/RLV And The Aerospike Engine
- Alloy Design
- Production
- Microstructure
- Mechanical Properties
- Thermal Properties
- Environmental Effects
- Alternative Production Techniques
- Summary
- Future Work

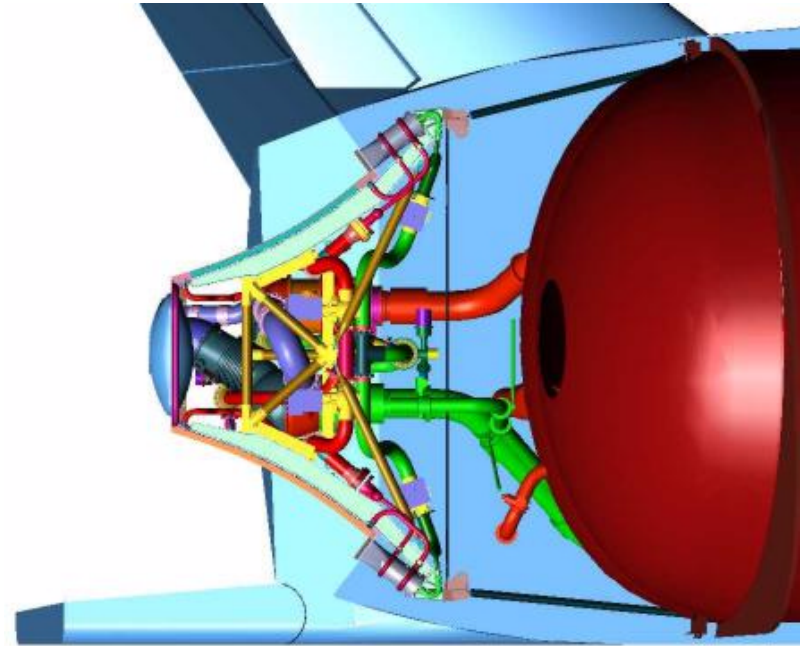
X-33 Technology Demonstration Vehicle



Length	63 ft
Width	68 ft
Take-off weight	273,000 lbs
Fuel	LH2/LO2
Fuel weight	210,000 lbs
Main Propulsion	(2) j-2s Linear Aerospike (10 thrusters per engine)
Take-off Thrust	410,000 lbs
Maximum Speed	Mach 15+

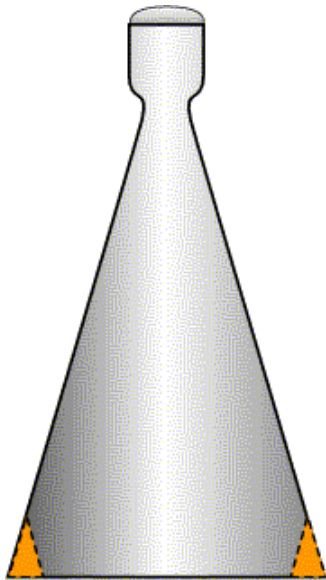
- X-33 is 53% scale model of Lockheed-Martin's VentureStar
- VentureStar will be 127 feet long, have a take-off weight of 2,186,000 pounds and use seven engines with 14 thrusters each developing a total of 3,017,000 pounds of thrust

Integration Of The Aerospike Engines With The Airframe

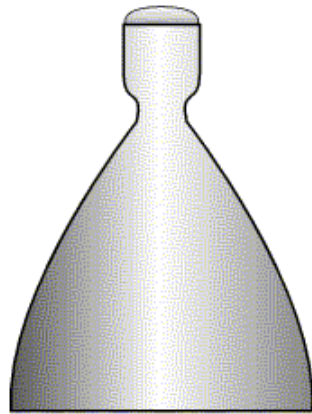


- The engines will be an integral part of the rear of the X-33
 - Reduced aerodynamic drag
 - Lower airframe weight

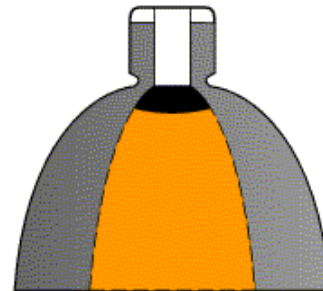
Different Types Of Nozzle Shapes



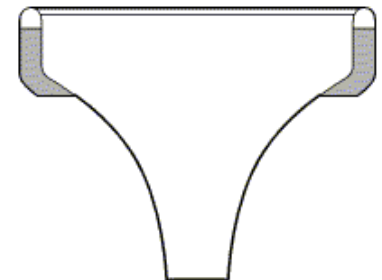
Cone



Bell

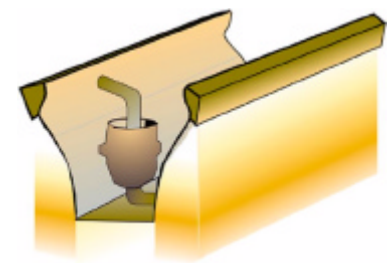
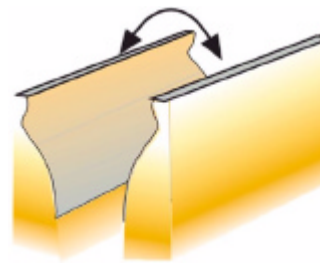
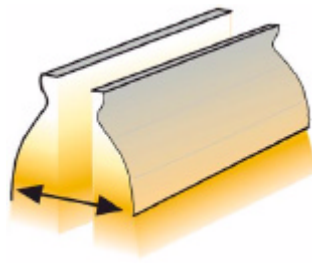
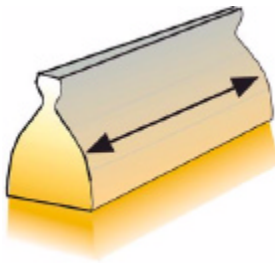
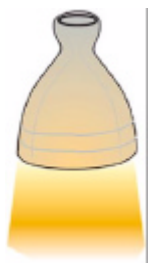


Expansion
Deflection

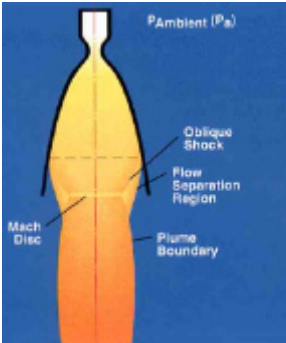
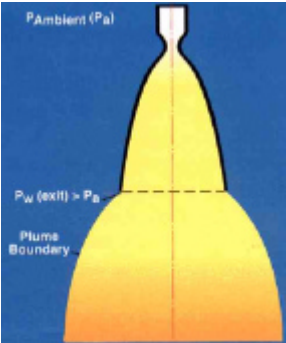
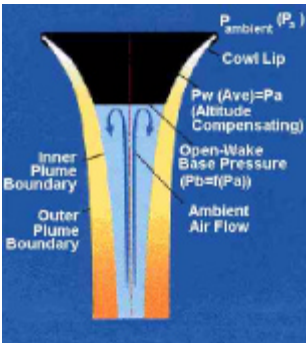
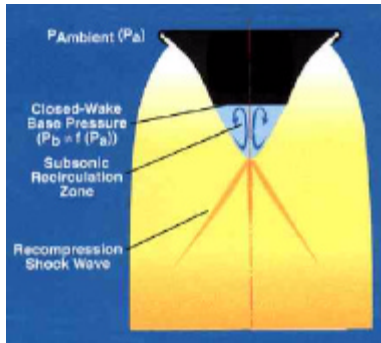


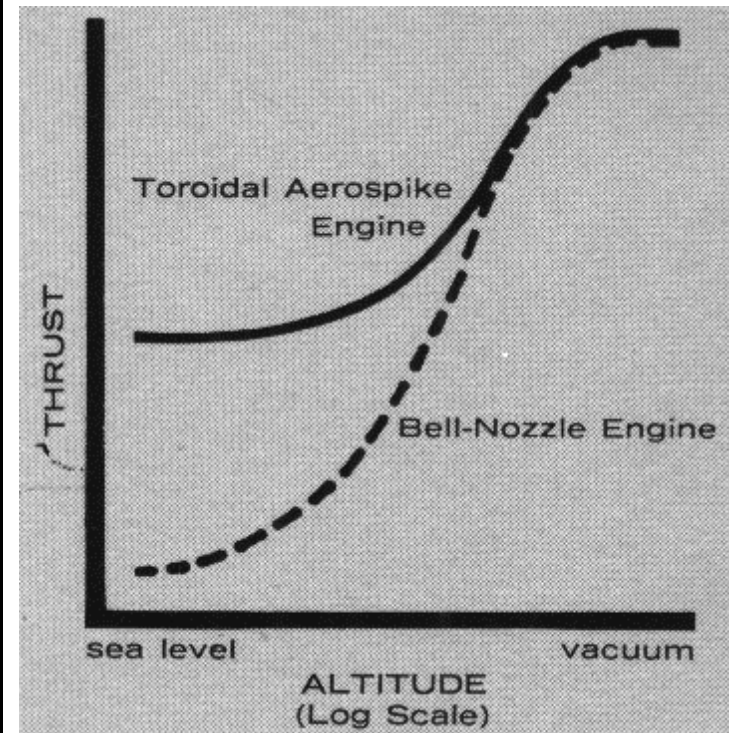
Aerospike

The aerospike engine is just one of several different nozzle shapes



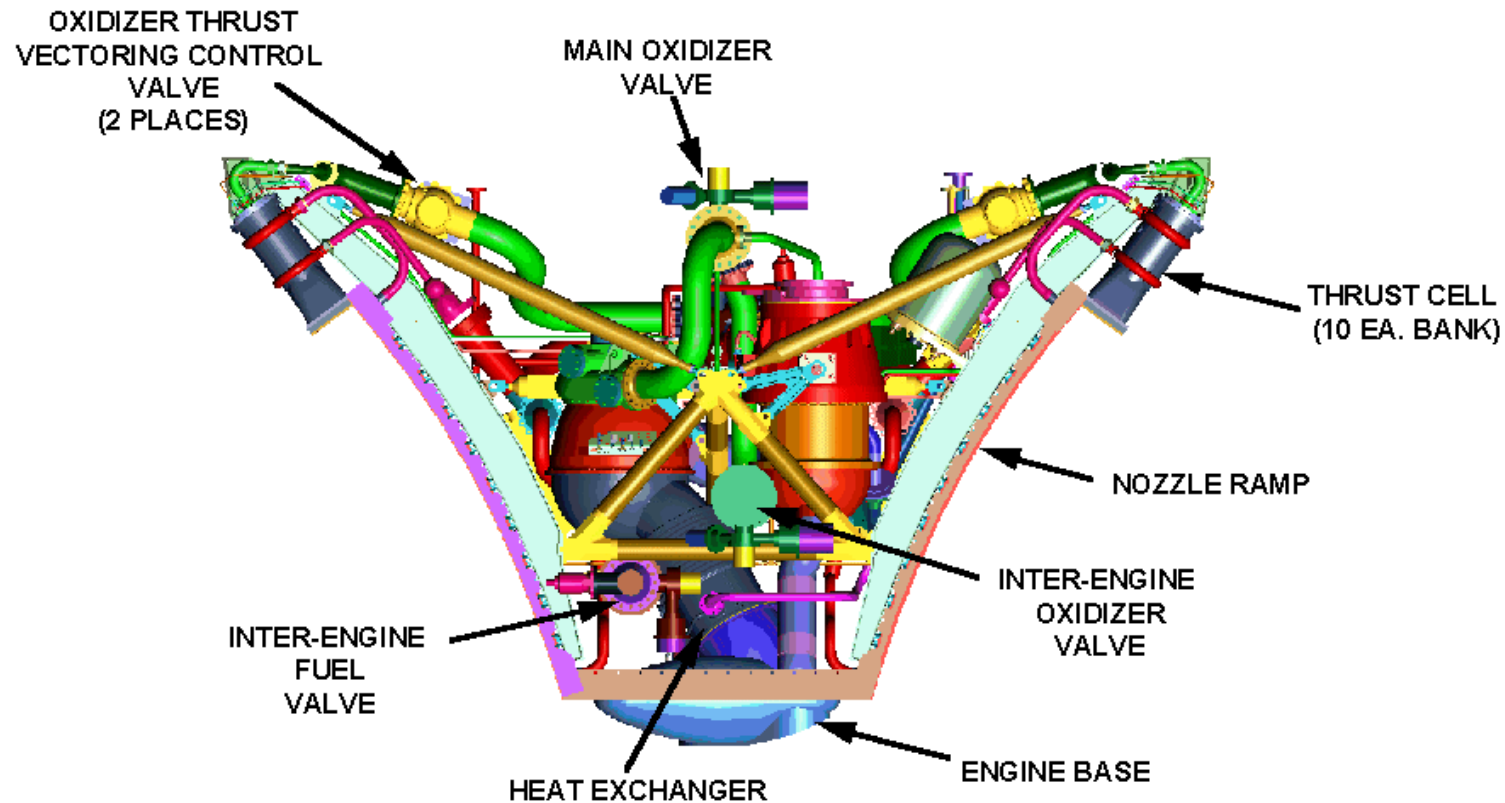
Aerospike Performance Advantages

	Liftoff	Space
Bell Nozzle		
Aerospike Engine		



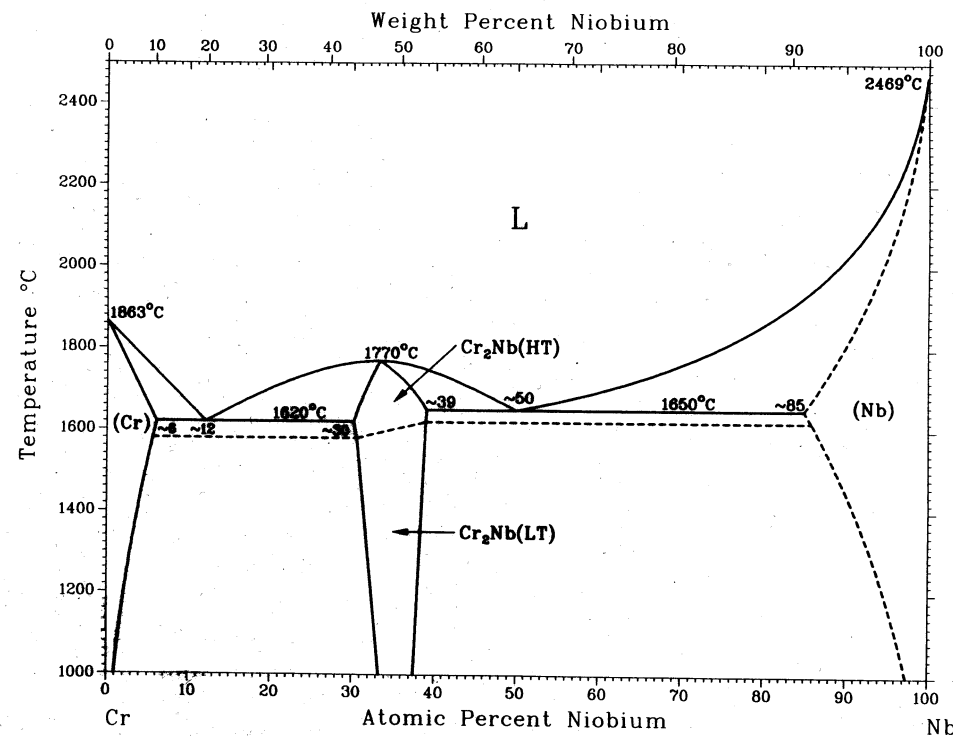
Aerospike engines produce more thrust over a wider altitude range than bell nozzles

Where Will Cu-Cr-Nb Alloys Be Used?



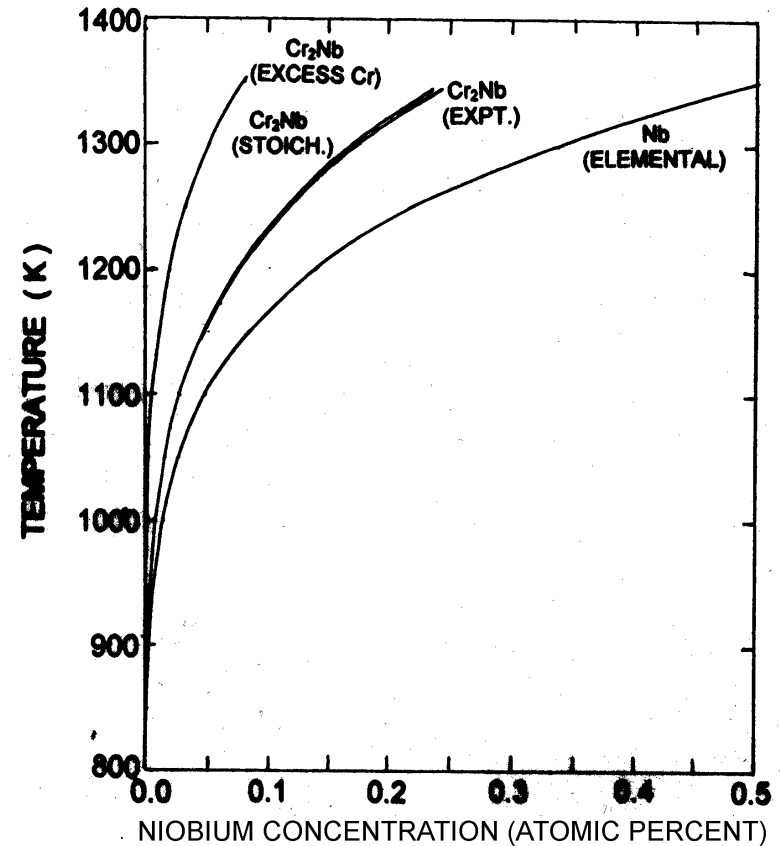
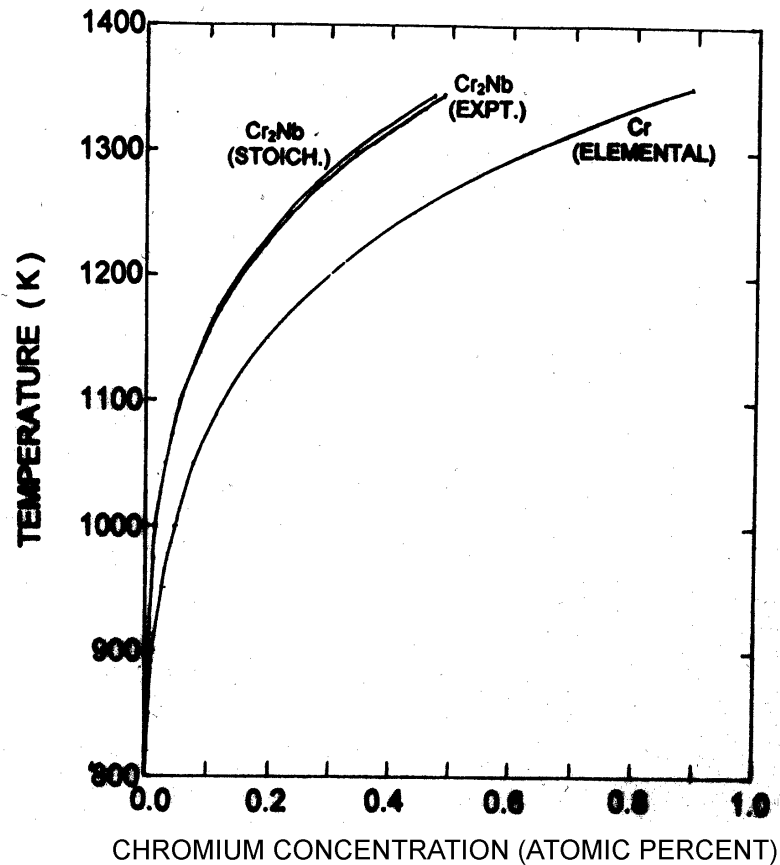
- Thrust Cell Combustion Chamber Liners
- Upper portion of Nozzle Ramp

Designing Cu-Cr-Nb Alloys



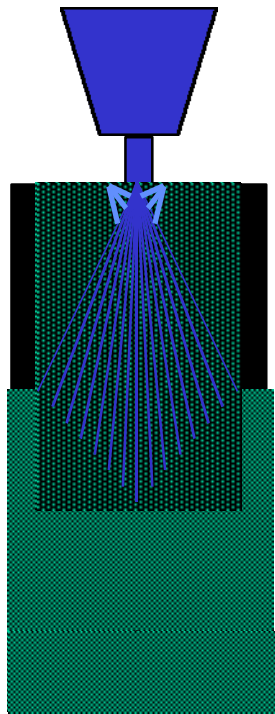
- Cu has second highest thermal conductivity among metals
- Cr and Nb have low solubility in Cu
- Nb has very low diffusivity in solid Cu
- Cr₂Nb is high melting point, hard intermetallic
- Use of rapid solidification technique should produce precipitation or dispersion strengthened alloy

Designing Cu-Cr-Nb Alloys (Cont.)



Pseudo-Binary Cu-Cr₂Nb Phase Diagrams

Production of Cu-8 Cr-4 Nb

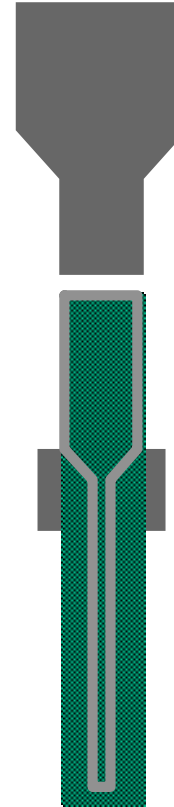


Starting materials are melted to produce a uniform liquid

A molten metal stream is introduced into an Ar filled chamber. High pressure Ar jets atomize the stream and cool the molten metal.

Powder is collected at the bottom of the chamber

Argon Gas Atomization

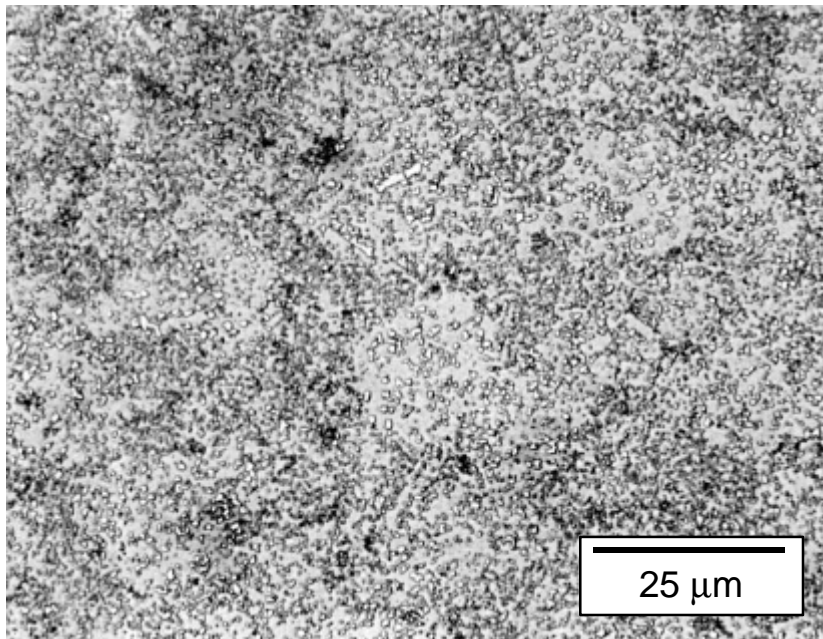


Vertical extrusion press applies up to 1311 MPa (190 ksi) force

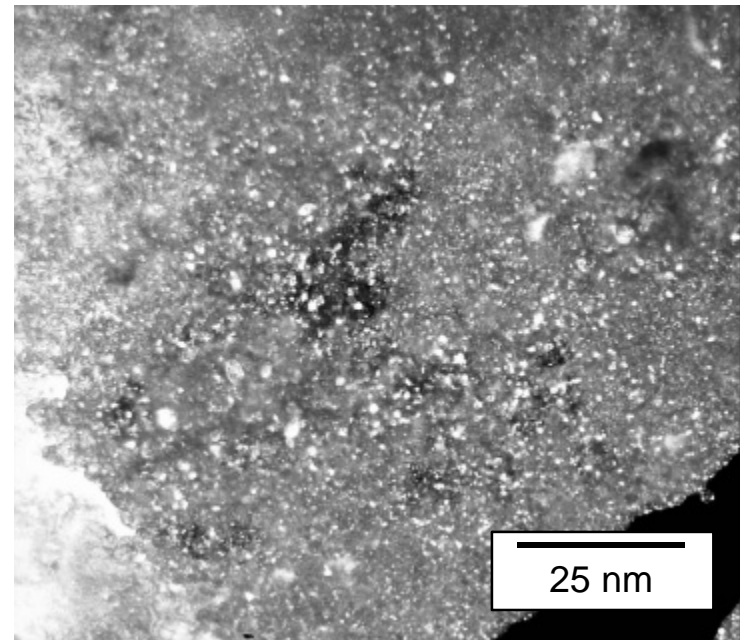
Canned powder extruded to consolidate material and form bar
16:1 Reduction in area round die used for extrusions

Extrusion

Cu-Cr-Nb Microstructure



Optical DIC

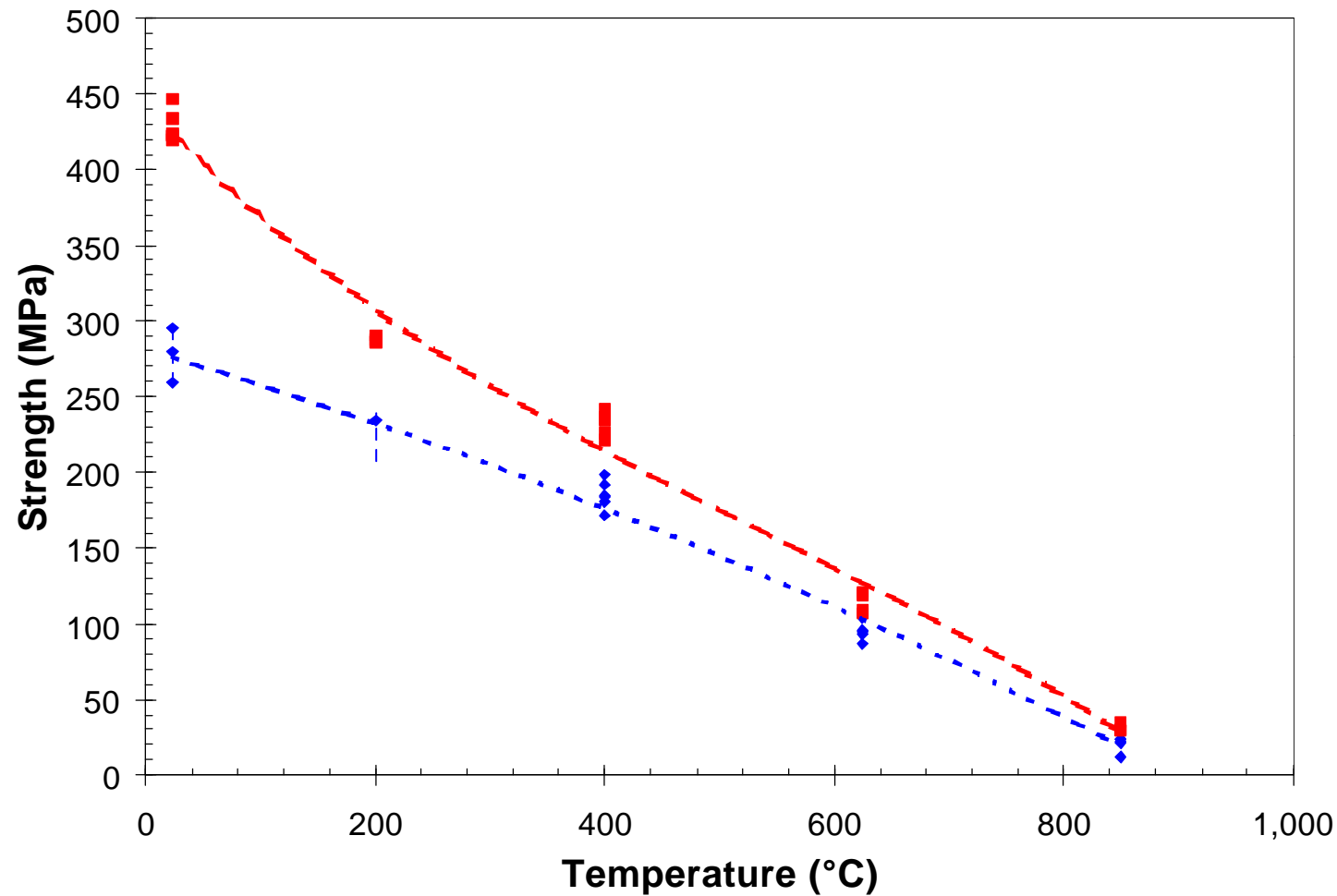


Dark Field TEM

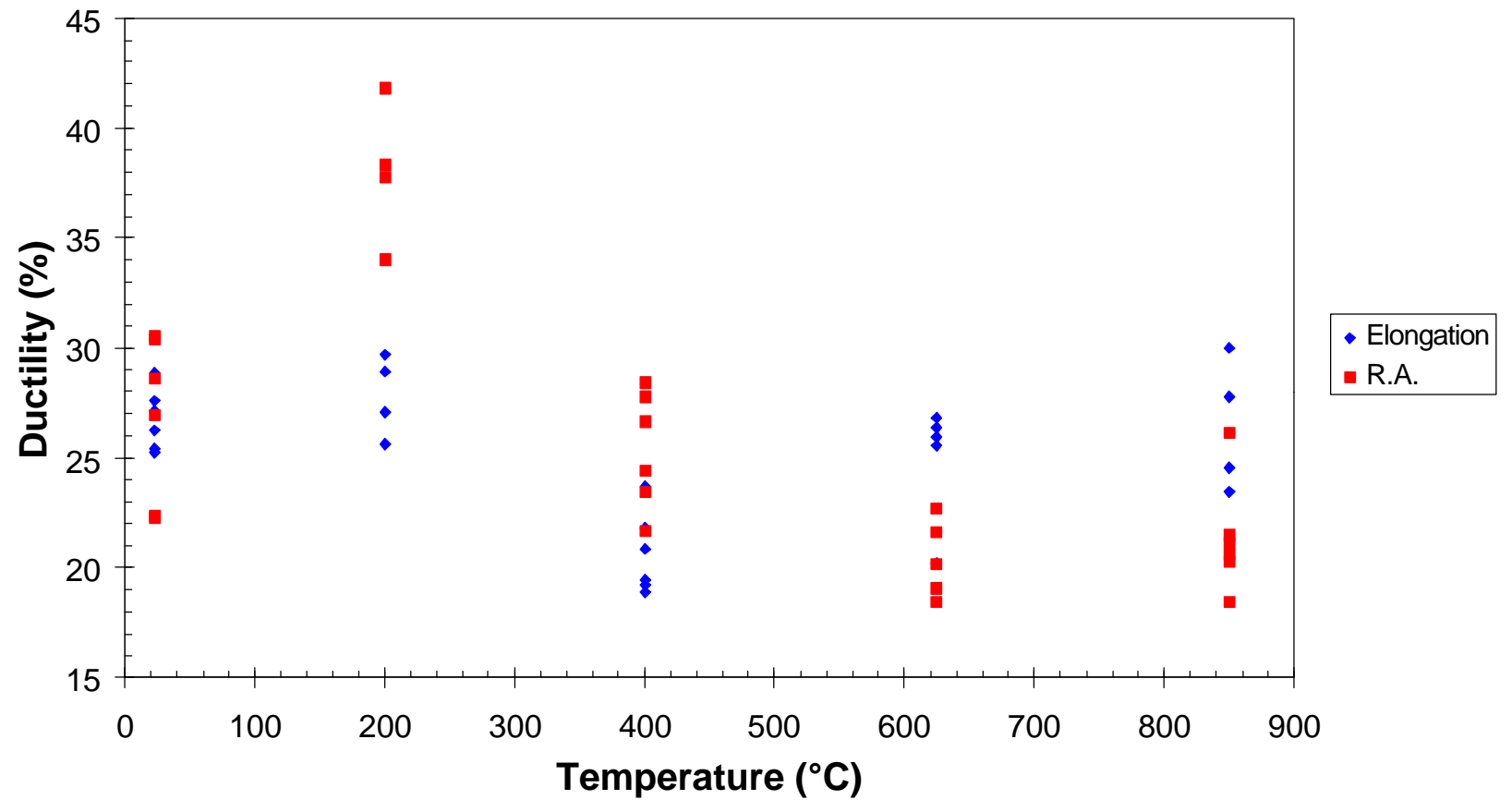
Phases identified:

- Cu matrix
- Cr_2Nb precipitates (main precipitate)
- Cr precipitate (minor precipitate)
- Some oxides, mainly Cr_2O_3

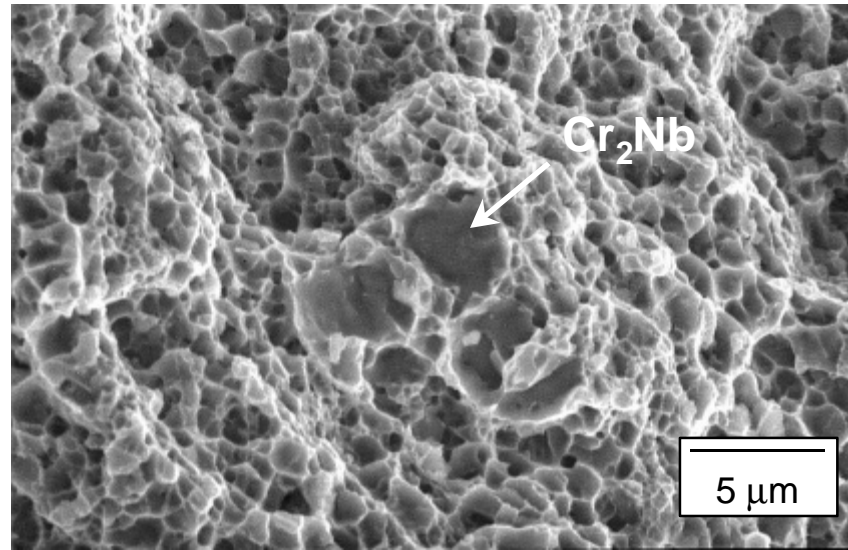
Tensile Strength Of Cu-8 Cr-4 Nb



Tensile Ductility Of Cu-8 Cr-4 Nb



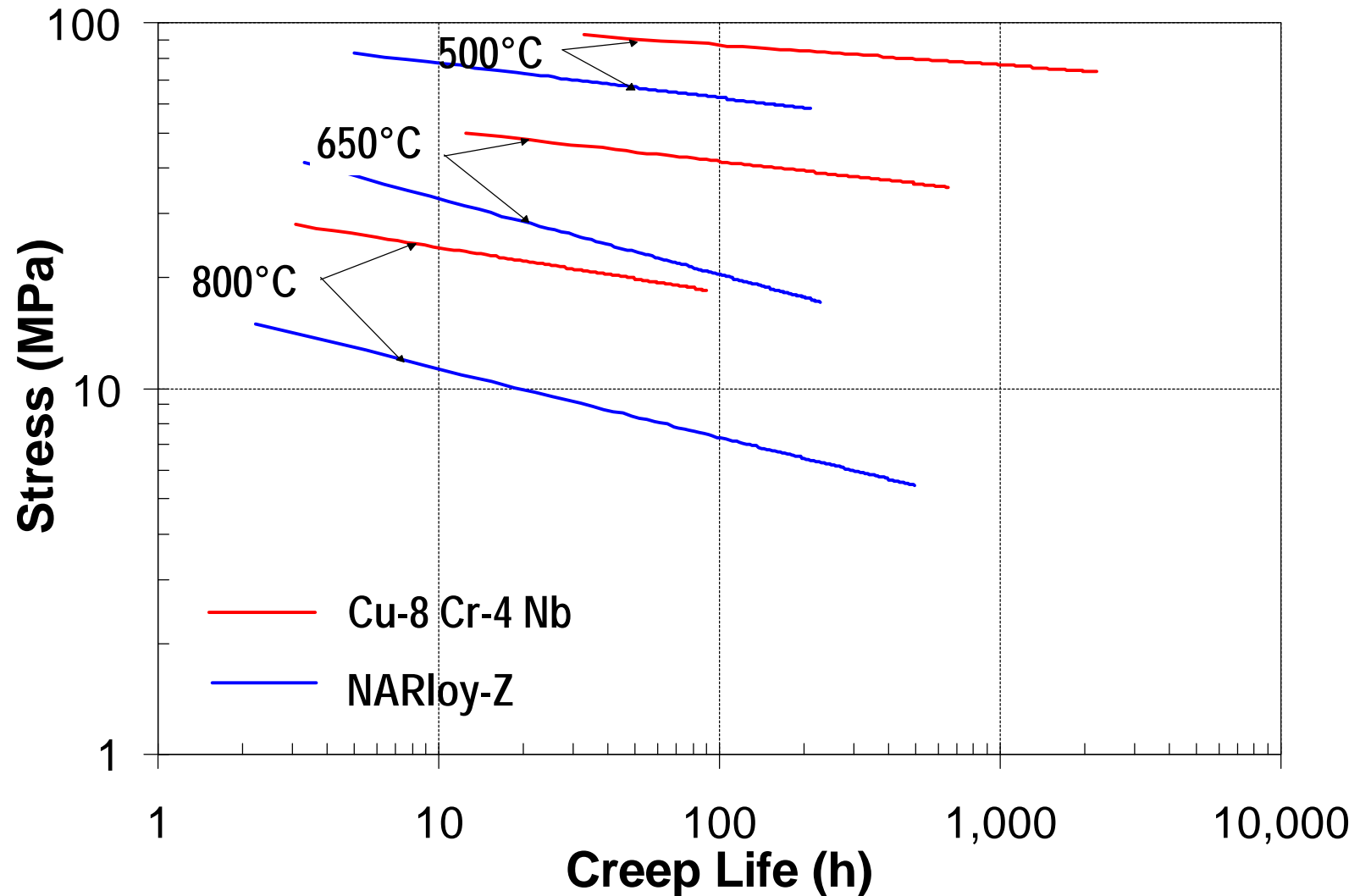
Tensile Test Fracture Surfaces



RT Cu-8 Cr-4 Nb Tensile Test

- Evidence of ductile failure
- No cleavage observed
- No debonding around precipitates observed
- No change in mode with temperature observed

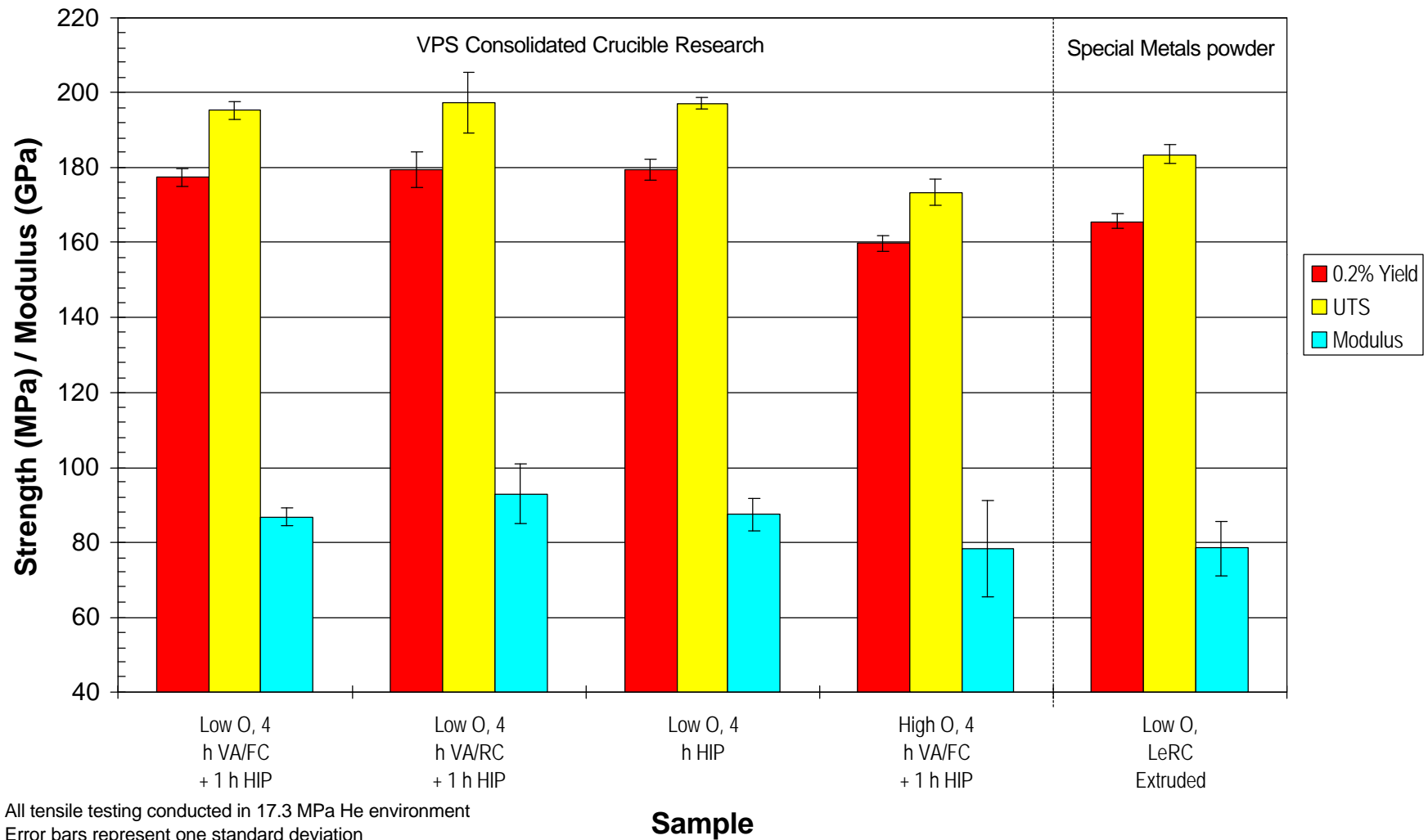
Creep Lives Of Cu-8 Cr-4 Nb



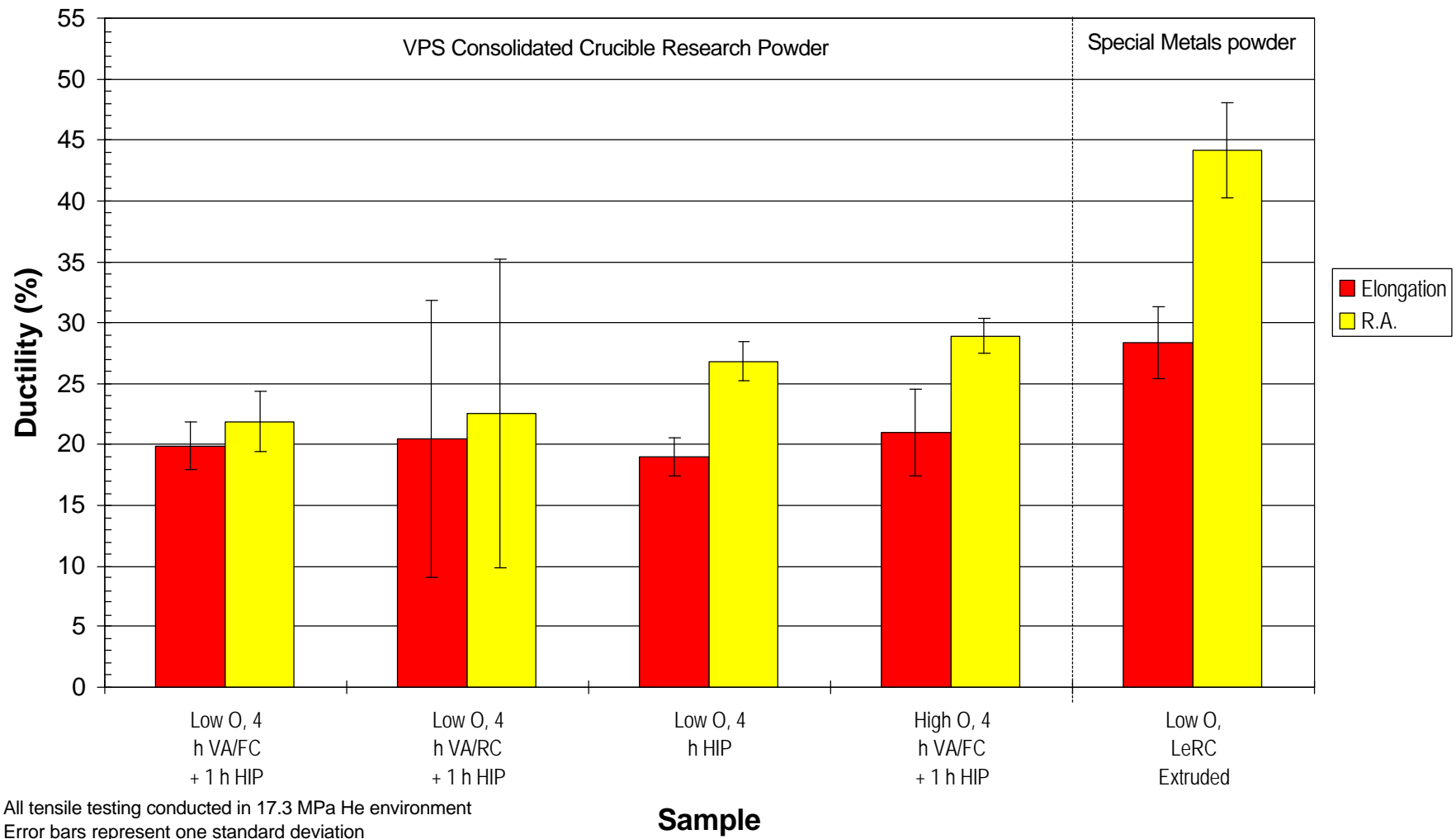
Alternative Production And Processing Methods

- Cryomilling
 - Capable of producing highly refined microstructures
 - Currently being pursued by UC-Davis and NASA LeRC
- Hot Isostatic Pressing (HIPing)
 - Capable of producing complex parts
 - Currently being pursued by Rocketdyne
- Vacuum Plasma Spraying (VPS)
 - Capable of spraying complex shapes
 - Can also incorporate functional gradient coating in material for environmental protection
 - Currently being pursued by NASA MSFC with LeRC support
- Casting
 - Low alloy content heat treatable Cu-Cr-Nb alloys
- Warm Rolling
 - Make thin sheet and more complex parts

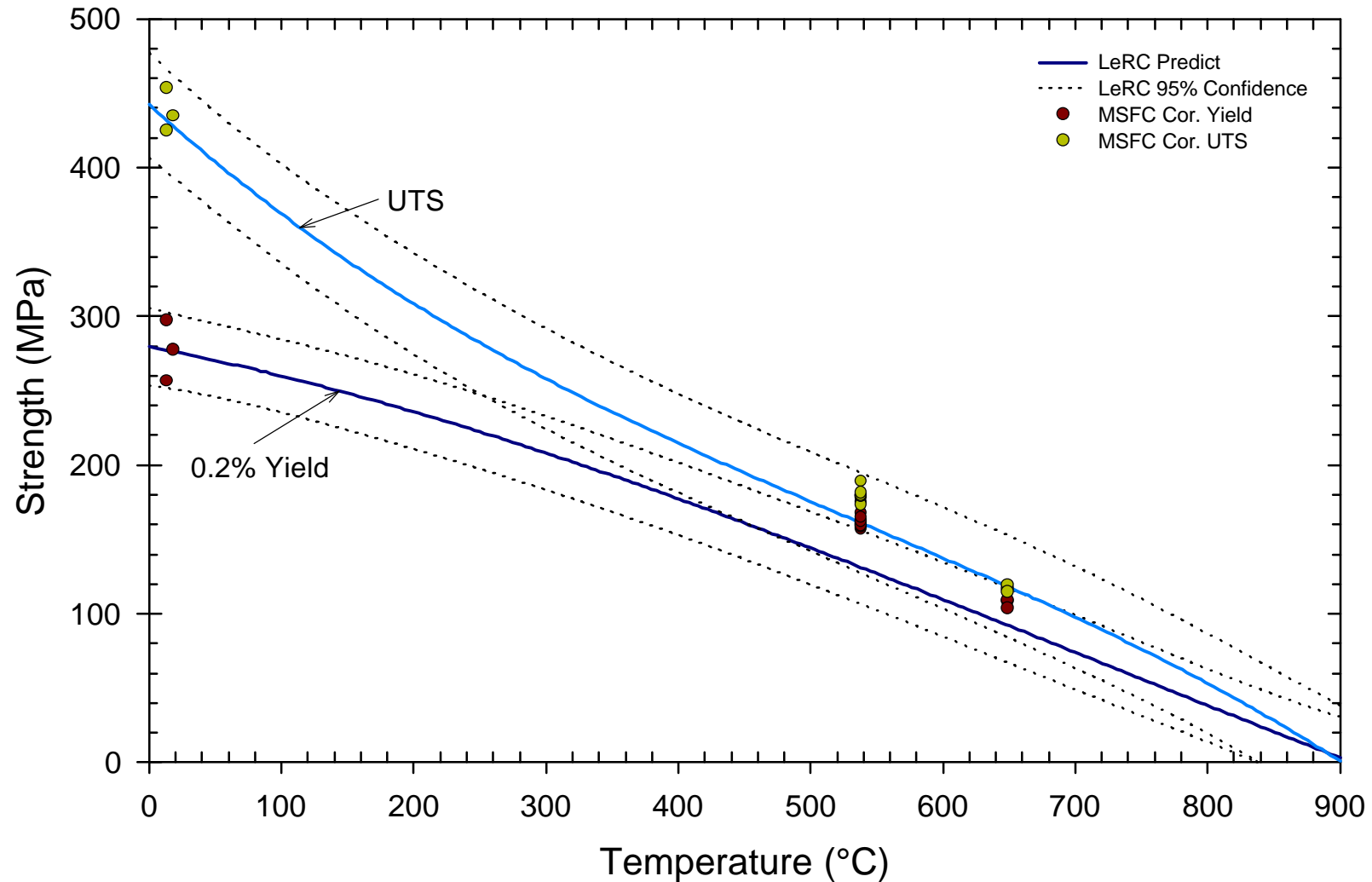
Effect Of Processing And Oxygen On 538°C Tensile Strength



Effect Of Processing And Oxygen On 538°C Tensile Ductility



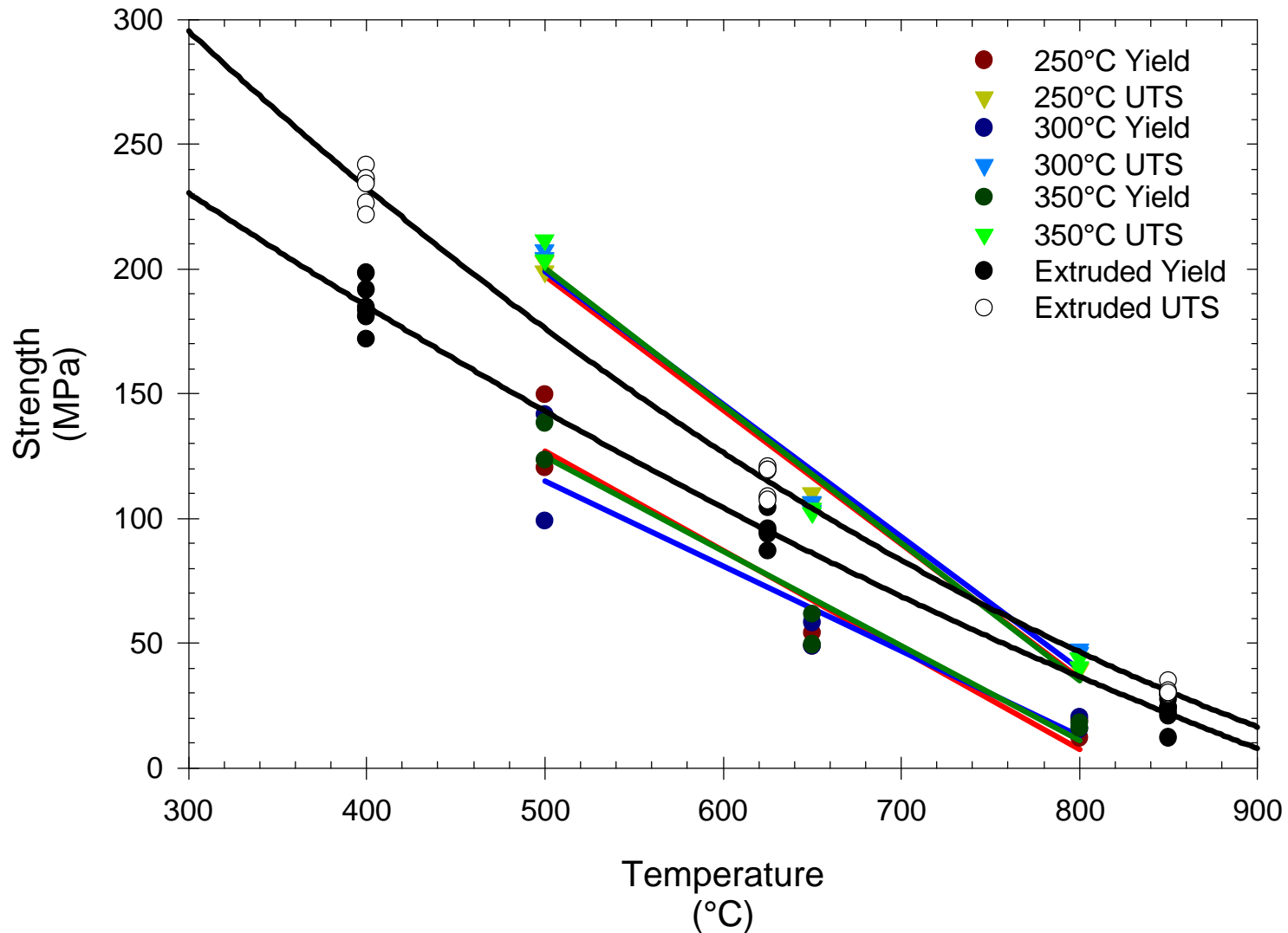
Comparison of VPS And Extruded Tensile Properties



Effect Of VPS And Extrusion On Mechanical Properties

- Yield strength
 - Vacuum anneal did not affect yield strength
 - HIP time did not affect strength
 - Low oxygen gave highest yield strengths, high oxygen lowest yield strength
 - Low oxygen VPS material was better than extruded material
- UTS
 - Same results as yield
- Elongation
 - No statistically significant differences
- Reduction in area
 - VPS material had lower R.A. than extruded material
- All comparisons made that the 95% confidence level

Tensile Strength Of Warm Worked Cu-8 Cr-4 Nb



Summary

- Cu-Cr-Nb alloys are an attractive alternative to NARloy-Z in thrust cell liner applications
 - Higher strength
 - Greater creep resistance
 - Longer LCF lives
 - Lower thermal expansion
 - High thermal conductivity

Future Work

- Develop a design level database of important properties
- Explore lower cost alternatives
 - Cryomilled alloys
 - Cast and rolled alloys